CIVL - 7904/8904

TRAFFIC FLOW THEORY

LECTURE -21

Agenda for Today

- Today-
  - Revision
  - Project report and presentation formats
  - Submit Assignment-4
  - Next classes:
    - May 6: Final
    - May 8: Presentation

After Mid-Term Exam (1)

- Modeling motion of a single vehicle
  - Case of constant speed
  - Case of constant acceleration
  - Case of varying acceleration
  - Equations of motion as a functions of speed and distance
  - Vehicle trajectories

After Mid-Term Exam (2)

- Modeling motion of group of interacting vehicles (Car Following Theory)
  - Pipe's theory
  - Forbe's theory
  - General Motor's five models
  - Gipps Model
  - Car Following Theory Application
  - Tracking two vehicle problem
  - Plotting the data and analyzing results

After Mid-Term Exam (3)

- Fundamentals of pre-timed signal timing design
  - Development of signal timing phase plans
  - Procedural steps for signal timing design
  - Important terms: cycle length, phase, interval, all red, yellow, green, saturation flow, peak hour factor, critical lane volume, lost time
  - Pedestrian requirements
  - Lag lead signal timings

After Mid-Term Exam (4)

- Fundamentals of actuated signal timing design
  - Actuation types
  - Detector types and detection technologies
  - Operation of actuated signals
  - Actuated signal timing and design

After Mid-Term Exam (5)

- Traffic flow fundamentals using detectors
  - Single detector system
  - Two detector system
  - Microscopic characteristics
  - Macroscopic characteristics

After Mid-Term Exam (6)

- Highway capacity software
- Paramics
- Synchro
- Visit to Region-4 TMC

After Mid-Term Exam (7)

- Shock Wave Analysis
  - Shock wave speed
  - Forward and backward shockwave
  - Application in recurring congestion
  - Application during incidents
  - Number of vehicles affected because of shock wave
  - Queue length
  - Time to clear the queue

Delay

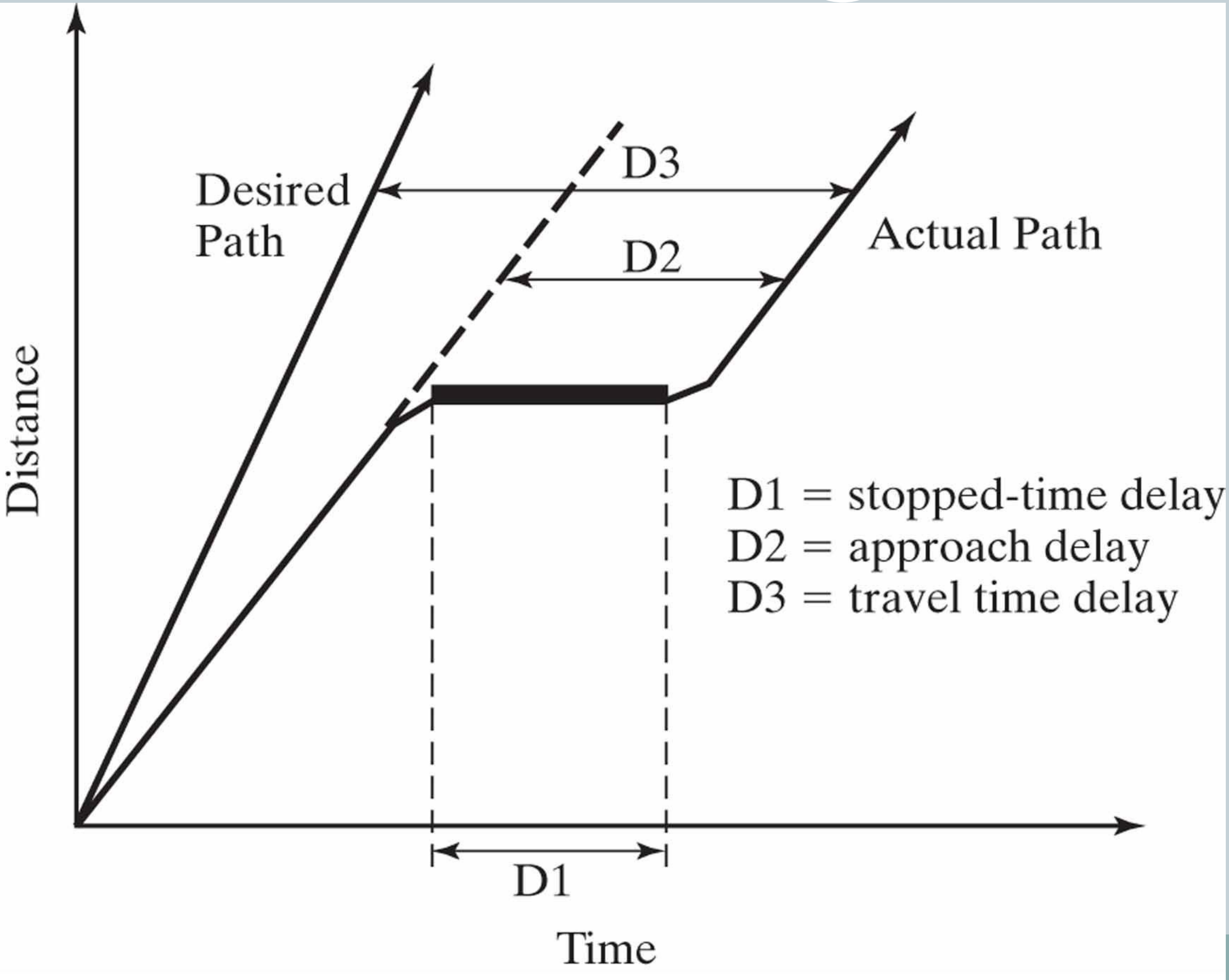
- The most common measure used to describe operational quality at a signalized intersection is delay.
- Delay refers to the amount of time consumed in travelling the intersection
  - The difference between the arrival time and departure time

Forms of Delay

- Stopped time delay
  - Defined as the time of a vehicle is stopped in queue while waiting to pass through the intersection
  - Average stop time delay is the average of all vehicles during a specified time period
- Approach delay
  - Included stopped delay
  - but adds the time loss due to deceleration from the approach speed to a stop and the time loss due to reacceleration back to desired speed

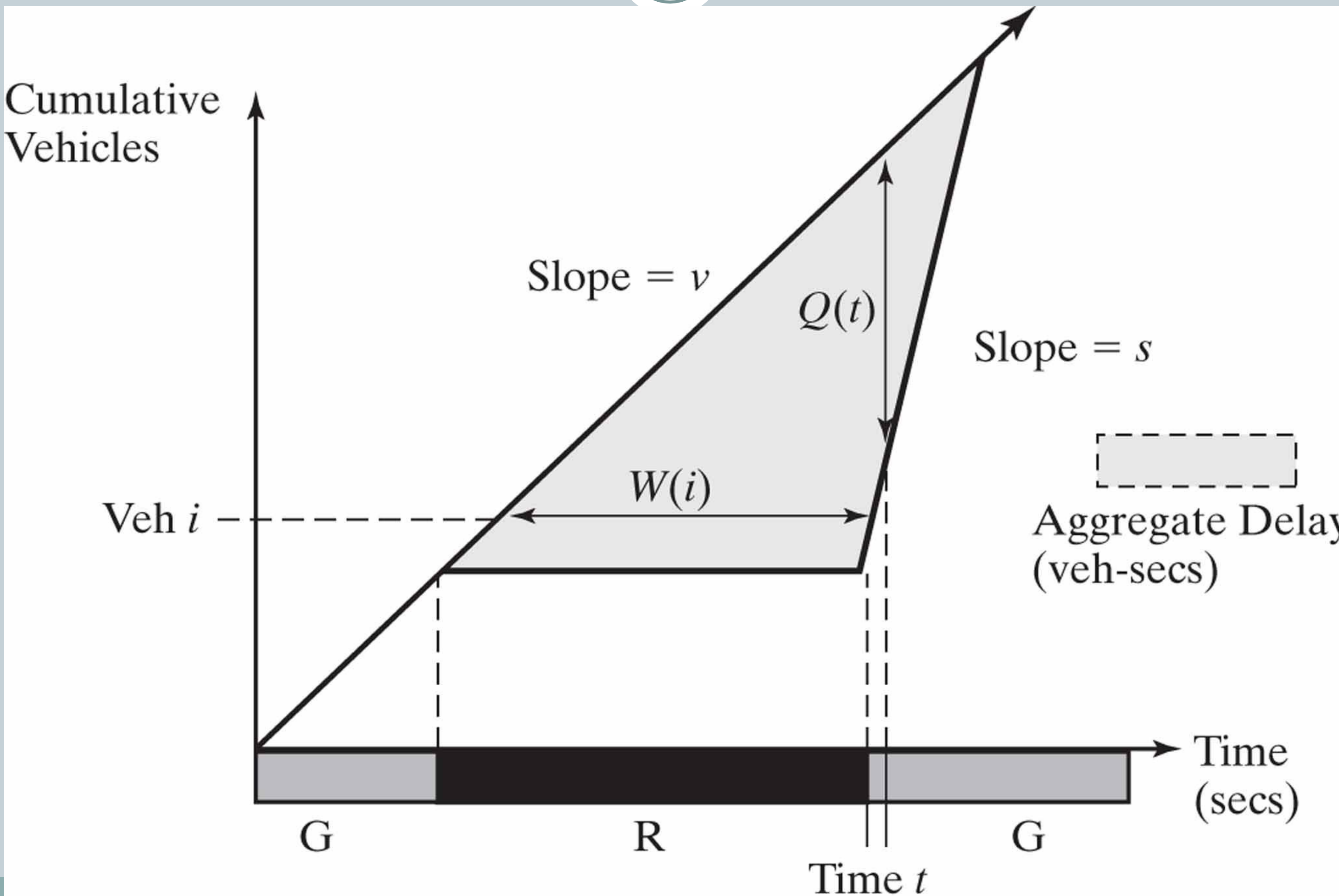
- Time-in-queue delay
  - Defined as the total time from a vehicle joining an intersection queue to its discharge across the STOP line on departure
- Travel time delay
  - More of a conceptual value
  - Difference between driver's expected travel time through the intersection and the actual time taken.
  - Difficult to obtain "desired" value, so this is a philosophical concept
- Control delay
  - Delay caused by the control device (either a traffic signal or stop sign)
  - Approximately = time-in-queue delay + acceleration-deceleration delay

Delay Measures



Average delay is measured as sec/vehicle

Basic Theoretical Models of Delay



Delay Components

- Assuming no pre-existing queue vehicles arriving when the light is green continue through the intersection
- When the light turn RED, vehicles arrive but do not depart
- Thus departure curve is parallel to the x-axis during RED interval

Delay Components (1)

- When the next effective GREEN begins, vehicles queued during RED intervals depart from the intersection
- Departure curve “catches up” with the arrival curve before the next RED interval begins

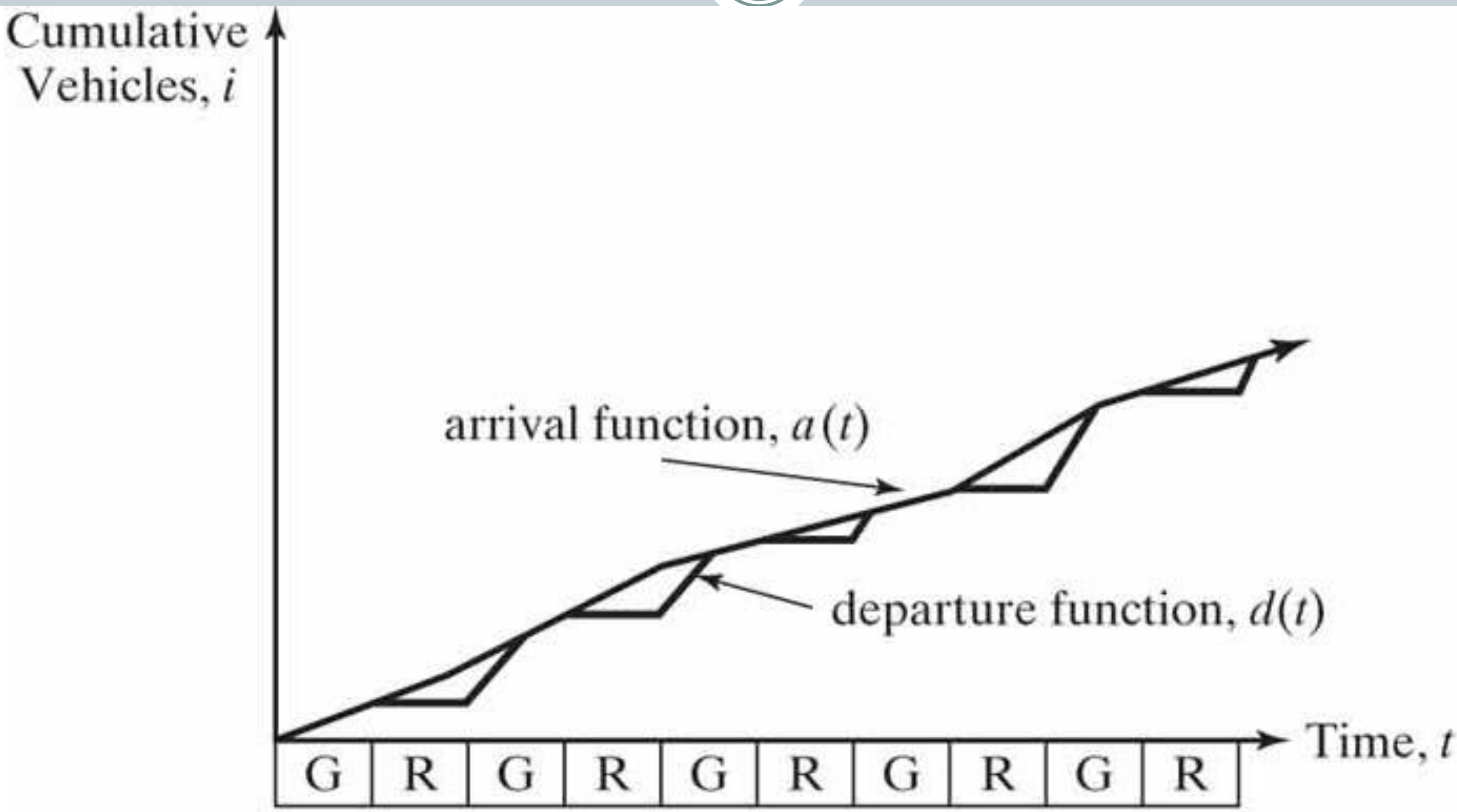
Delay Components (2)

- The total time that any vehicle "*i*" spends waiting in the queue, W(i) is given by the horizontal time-scale difference between the time of arrival and the time of departure
- The total number of vehicles queued at any time t, Q(t), is the vertical scale difference between the number of vehicles that have arrived and the number of vehicles that have departed.

Delay Components (3)

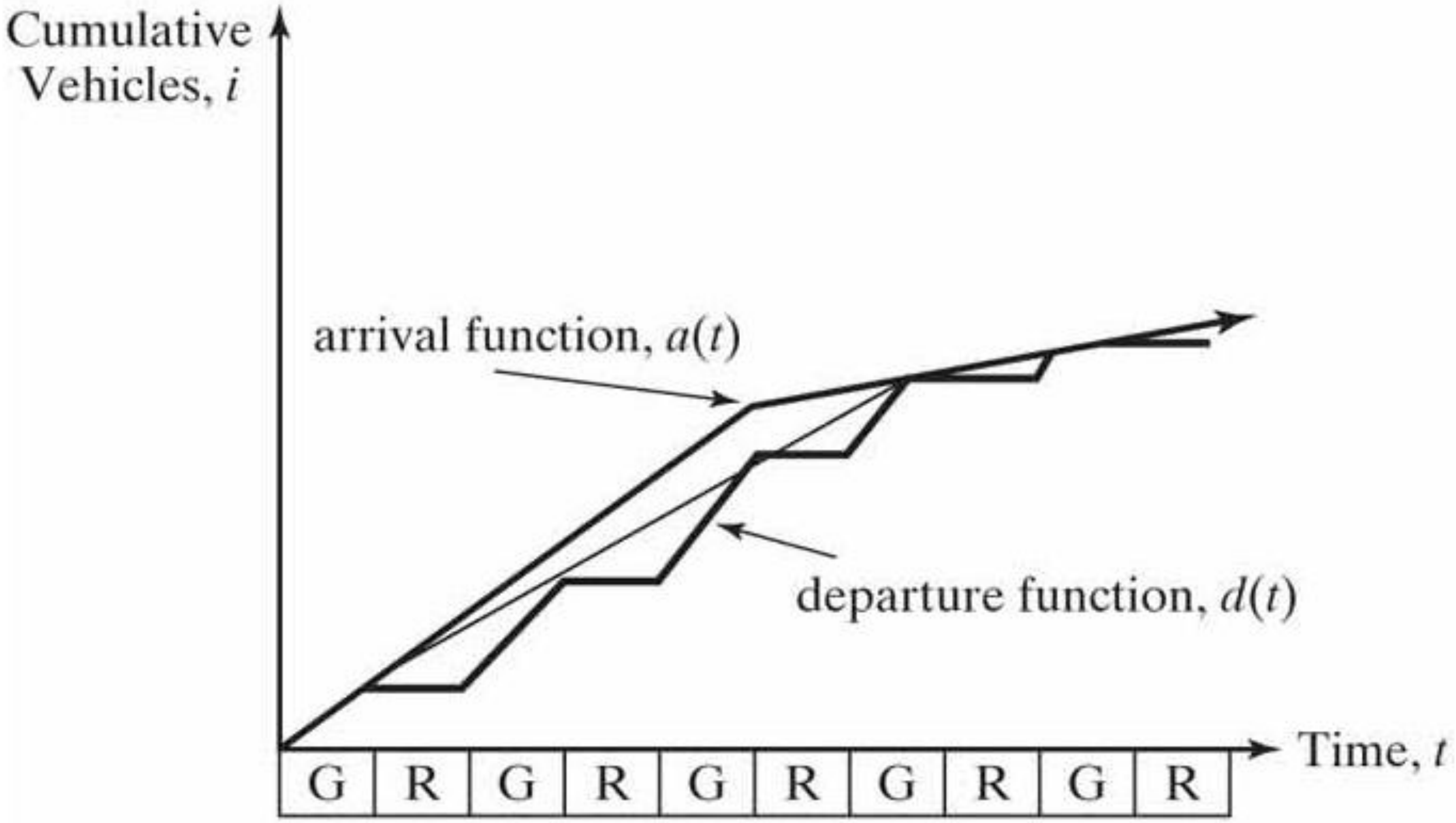
- The average delay for all vehicles passing through the signal is the area between the arrival and departure curve (vehicles x time)

Delay Scenario (1)



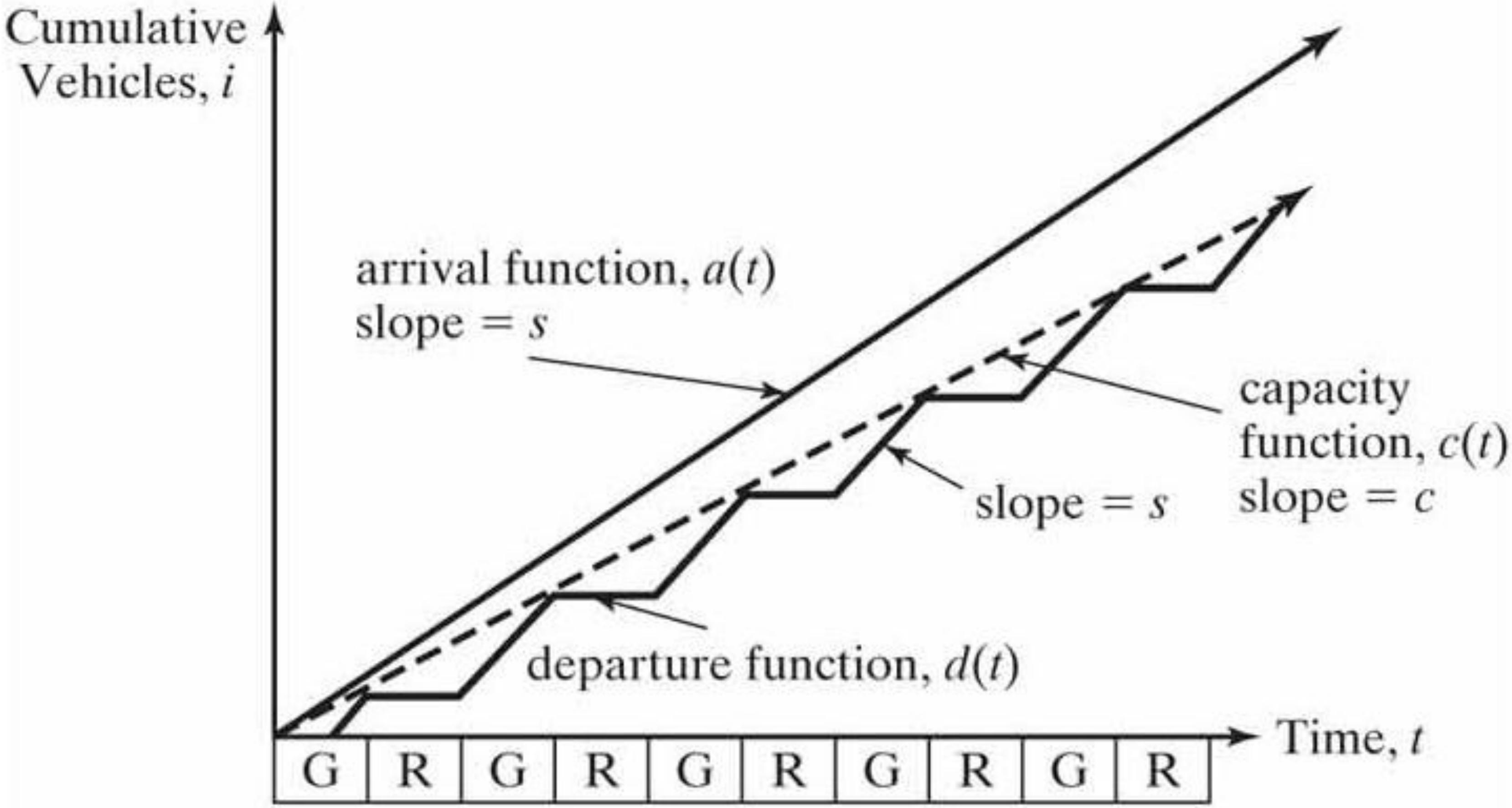
(a) Stable Flow

Delay Scenario (2)



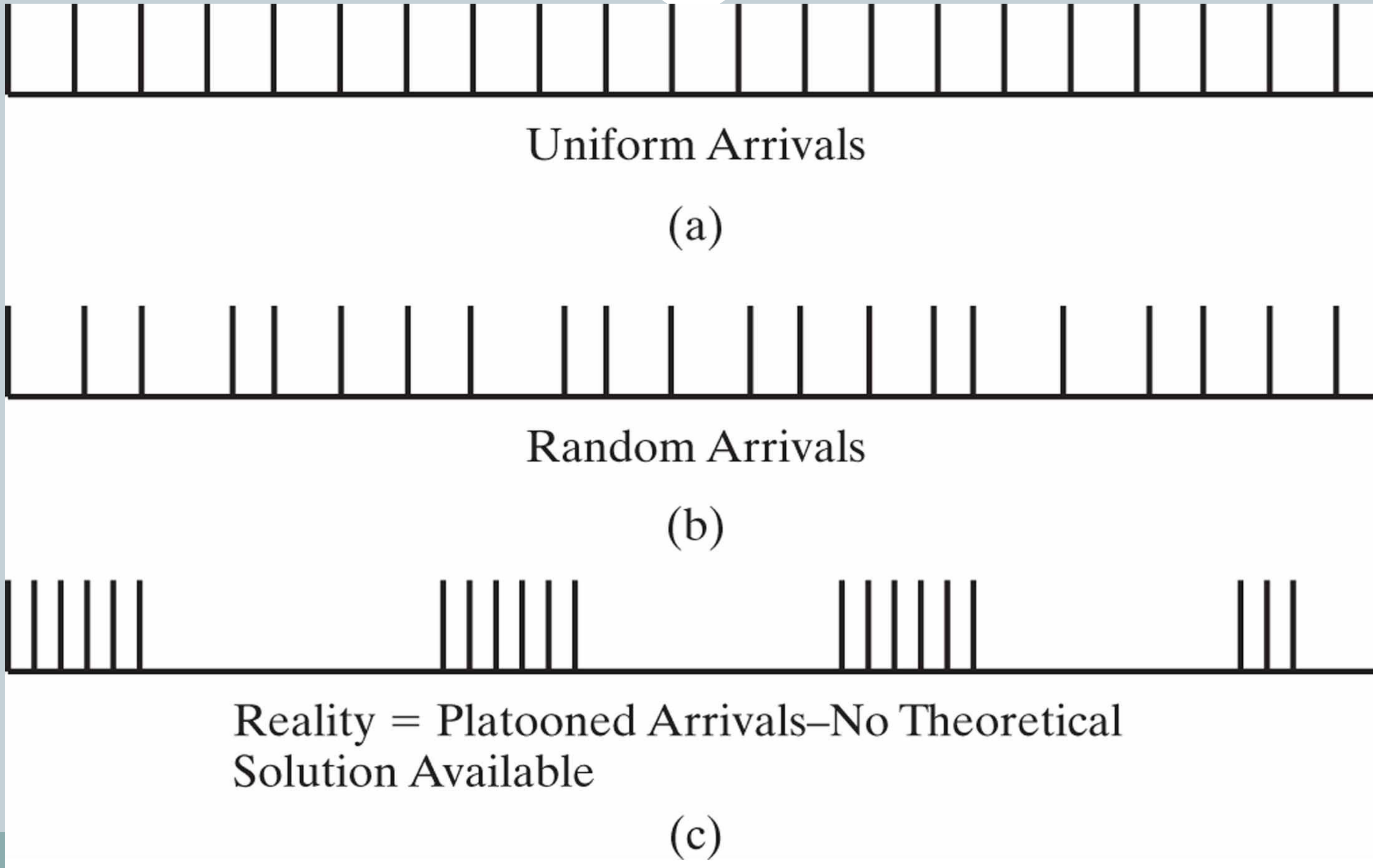
(b) Individual Cycle Failures
Within a Stable Operation

Delay Scenario (3)



(c) Demand Exceeds Capacity for a Significant Period

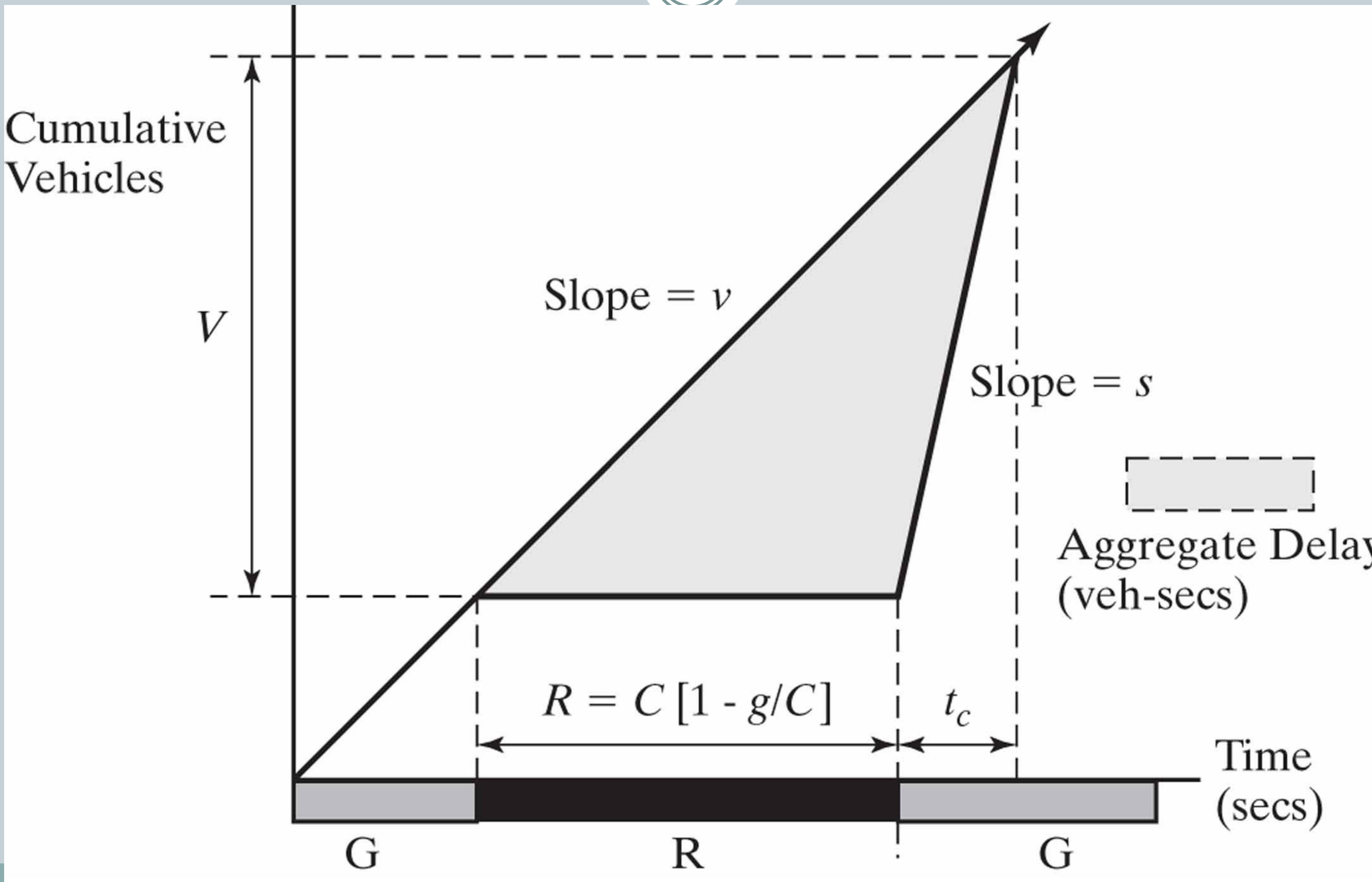
Arrival Patterns



Components of Delay

- Uniform Delay
  - Delay based on an assumption of uniform arrivals and stable flow with no individual cycle failures
- Random Delay
  - Additional delay above and beyond uniform delay because flow is randomly distributed rather than uniform at isolated intersection
- Overflow Delay
  - Additional delay that occurs when the capacity of an individual phase or series of phases is less than the demand or arrival flow rate

Webster's Uniform Delay



Uniform Delay

$$UD_a = 0.5RV$$

-> Aggregate uniform delay, veh-sec
-> length of red phase, sec
-> total vehicles in queue, veh

Where,

$$R = C\left[1 - \left(\frac{g}{C}\right)\right]$$

C -> cycle length, sec
g-> effective green time, sec

Derivation of Uniform Delay

Random Delay

- The uniform delay model assumes that arrivals are uniform and that no signal phases fail, i.e.
- Arrival flow is less than capacity during every signal cycle of the analysis period
- At isolated intersections, vehicle arrivals are more likely to be random
- A number of stochastic models have derived
- Such models assume that inter-vehicle arrival times are distributed according to Poisson distribution with underlying average arrival rate of υ vehicles per unit time

Random Delay

- Such models account for both the underlying randomness of arrivals and the fact that some individual cycles could fail because of randomness
- The additional delay is referred as "overflow delay", but it does not address *v/c>1.0*
- The most frequently used random delay as per Webster's formulation as below

$$RD = \frac{X^2}{2v(1-X)}$$

RD-> Average random delay per vehicle, sec/veh
X-> v/c ratio

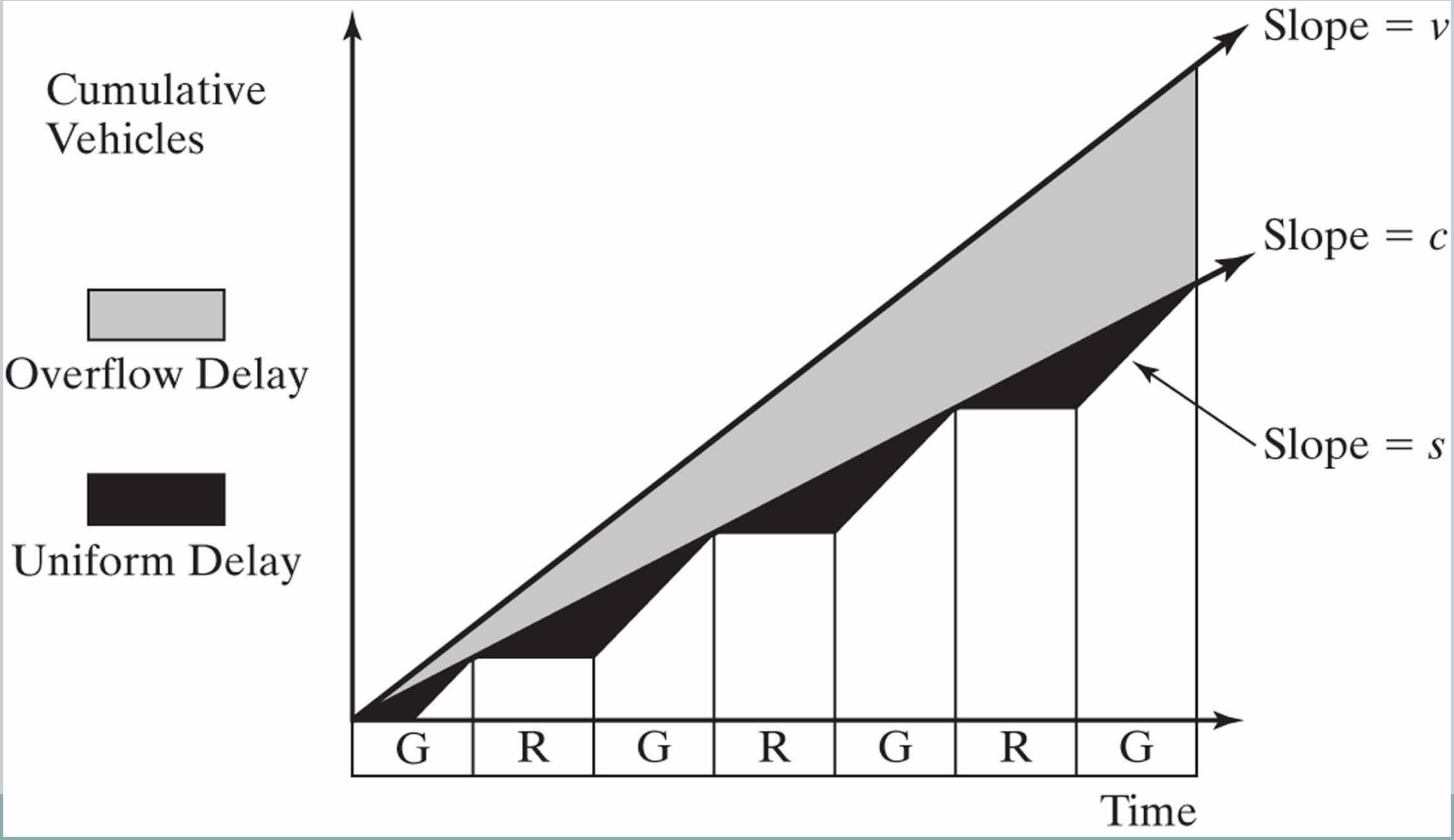
Total Delay

- The formulation found to somewhat overestimate delay, and Webster proposed total delay as following
- $D = 0.9(UD + RD)$, where D-> Sum of uniform and random delay

Overflow Delay

- Oversaturation is used to describe extended time periods during which arriving vehicles exceed capacity of the intersection approach to discharge vehicles
- In such cases queues grow and overflow delay, in addition to uniform delay accrues
- Because overflow delay accounts for the failure of an extended series of phases, it encompasses a portion of random delay as well

Delay in Oversaturated Period



Uniform Delay when X=1

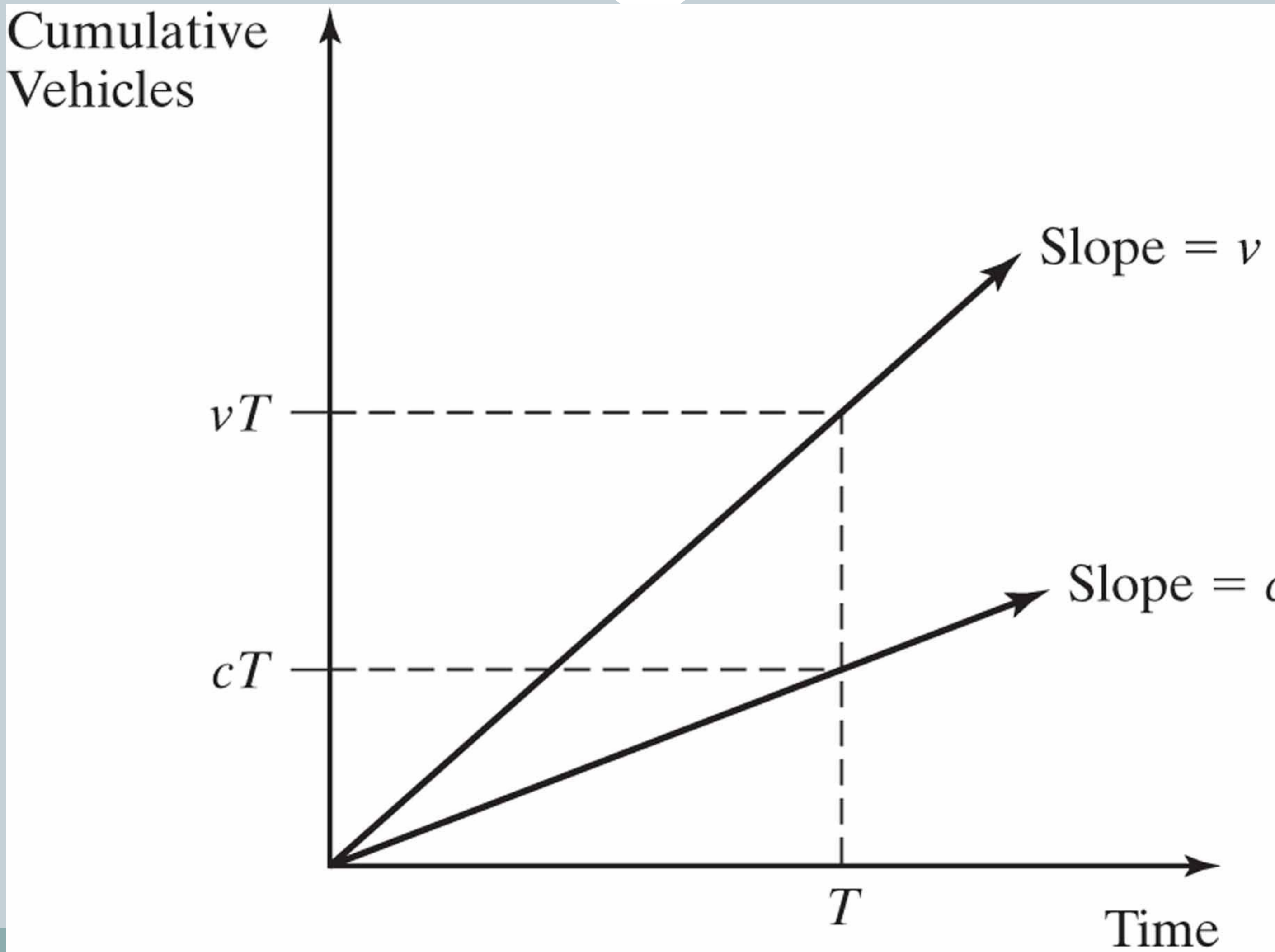
- Uniform delay when v/c = 1.0 is referred as UD_0

$$UD_0 = \frac{0.5C\left[1 - \left({}^{g}/_{c}\right)\right]^2}{1 - \left({}^{g}/_{c}\right)X}$$

When X=1

$$UD_0 = 0.5C\left[1 - \left({}^{g}/_{c}\right)\right]$$

Overflow Delay



Overflow Delay for a Time Period

$$OD_a = \frac{1}{2}T(vT - cT) = \frac{1}{2}T^2(v - c)$$

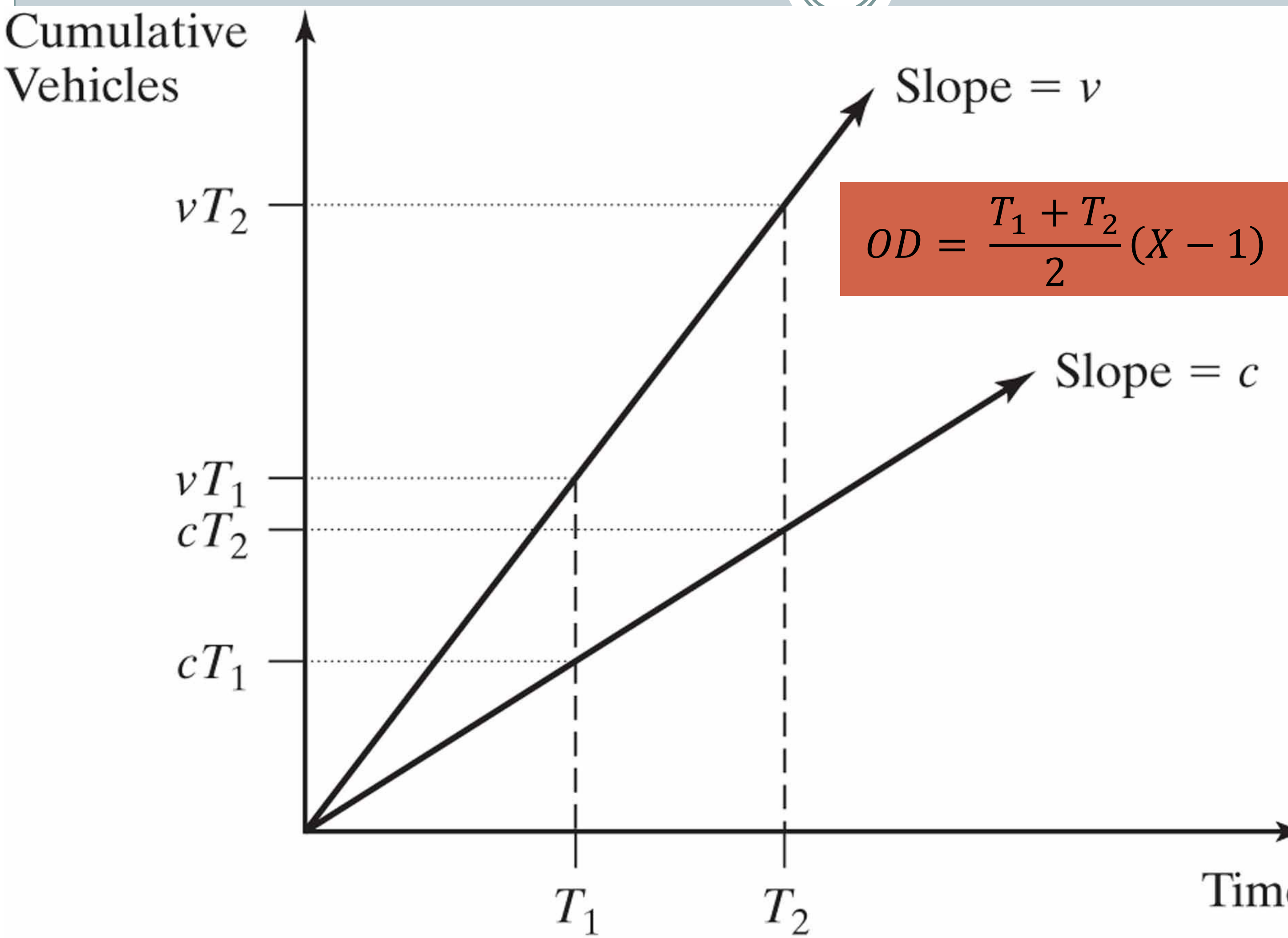
$$OD = \frac{T}{2}[X - 1]$$

Where,

OD_a-> Aggregate overflow delay, veh-sec

OD-> Average overflow delay per vehicle, sec/veh

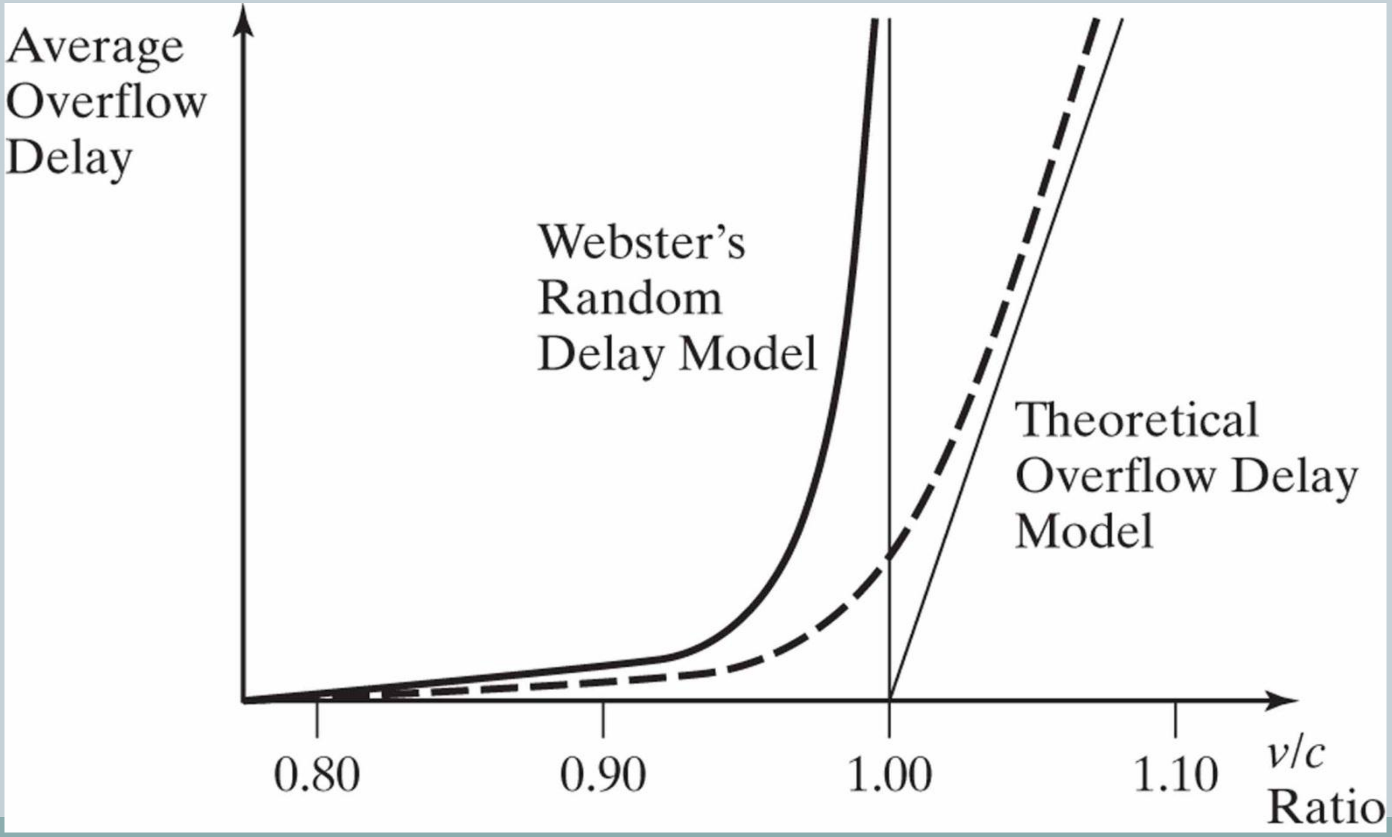
Overflow Delay Between Two Time Periods



$$OD = \frac{T_1 + T_2}{2}(X - 1)$$

Inconsistencies in Random and Overflow Delay (1)

- The inconsistency occurs when v/c is in the vicinity of 1.0



Inconsistencies in Random and Overflow Delay (2)

- If the v/c ratio is below 1.0, then a random delay model is being used
  - Because there is no overflow delay in this case

$$RD = \frac{X^2}{2v(1-X)}$$

RD-> Average random delay per vehicle, sec/veh
X-> v/c ratio

- As X approaches 1.0, random delay increases asymptotically

Inconsistencies in Random and Overflow Delay (3)

- When v/c ratio is greater than 1.0, then overflow delay model is applied

$$OD_a = \frac{1}{2}T(vT - cT) = \frac{1}{2}T^2(v - c)$$

$$OD = \frac{T}{2}[X - 1]$$

Where,
OD_a-> Aggregate overflow delay, veh-sec
OD-> Average overflow delay per vehicle, sec/veh

- However, when X=1, *OD=0*
- But increases uniformly with increasing values of X thereafter

Inconsistencies in Random and Overflow Delay (4)

- Neither model is accurate in the vicinity of X=1
- In terms of practical terms, most studies confirms that the uniform delay is a sufficient predictive tool (except the issue with platooned arrivals) when the v/c ratio is 0.85 or less.
- In this range the true value of random delay is miniscule and there is no overflow delay.

Inconsistencies in Random and Overflow Delay (5)

- Similarly, the simple theoretical overflow delay is a reasonable predictor when v/c >= 1.15
- The problem is that the most interesting case fall in the intermediate range
  - 0.85<v<1.15
- For which neither model is adequate
- Much of the recent work in delay modeling attempts to bridge this gap

Commonly used Formula

$$OD = \frac{cT}{4}\left[(X-1) + \sqrt{(X-1)^2 + \left(\frac{12(X-X_0)}{cT}\right)}\right]$$

Where,

$$X_0 = 0.67 + \left(\frac{sg}{600}\right)$$

T-> Analysis period, hrs
X-> v/c ratio
C-> Capacity, veh/hr
s-> Saturation flow rate, veh/sec/green
g-> Effective green time, sec

Example-1

- An intersection approach has an flow rate of 1000 veh/hr, a saturation flow rate of 2,800 veh/hr/gr, a cycle length of 90 sec, and g/C ratio of 0.55. What average delay per vehicle is expected under these condition?